LEPTON FLAVOR VIOLATION IN THE HIGGS BOSON DECAY AT A LINEAR COLLIDER

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We study possibility of observing the process $h^0 \to \tau^\pm\mu^\mp$ at a linear collider. The branching ratio is constrained to be of the order of 10^{-4} by the $\tau^- \to \mu^-\eta$ result. Supersymmetric standard models can reproduce such amount of the branching ratio by taking a specific parameter set. The Higgsstrahlung process $e^+e^- \to Zh^0$ is preferable because of its simple kinematic structure, then, the signal process is $e^+e^- \to Zh^0 \to Z\tau^\pm\mu^\mp$. The most serious background comes from the process, $e^+e^- \to Zh^0 \to Z\tau^\pm\tau^\mp \to \tau^\pm\mu^\mp\nu\bar{\nu}$. We estimate the significance of the signal, taking into account the background reduction.

1 Introduction

The search for the Lepton Flavor Violation (LFV) process is a promising way to find the signal of new physics. We propose a method to search for the LFV process $h^0 \to \tau^\pm\mu^\mp$ at a Linear Collider (LC). We can measure the LFV Yukawa coupling directly by this process, differently from the photon associated process $\tau \to \mu\gamma$ and the decays of a tau lepton $\tau \to \mu\mu\mu$ and $\tau \to \mu\eta$.

First, we show the experimental bound on the LFV Yukawa coupling. The strongest bound comes from the result of the $\tau^- \to \mu^-\eta$ search. Its upper limit can be realized in the Minimal Supersymmetric Standard Model (MSSM) with a specific parameter set. Next, we consider the signal process $e^+e^- \to Zh^0 \to Z\tau^\pm\mu^\mp$ and also study the background reduction. There is an irreducible background which we call *the fake signal*. We estimate the significance of the signal taking into account the event numbers of the signal and the fake. The details are shown in our recent work[1].

2 LFV Yukawa Coupling

The LFV Yukawa couplings are induced at the one-loop level in the MSSM. The effective Lagrangian is written as follows[2,3,4]:

$$\mathcal{L}_{\tau\mu} = -\frac{\kappa_{32} m_\tau}{v\cos^2\beta}(\overline{\tau_R}\mu_L)\left\{\cos(\alpha-\beta)h^0 + \sin(\alpha-\beta)H^0 - \mathrm{i}A^0\right\} + \mathrm{H.c.}. \quad (1)$$

Consequently, the branching ratio for $h^0 \to \tau^\pm \mu^\mp$ is approximately given by[a]

$$\mathrm{Br}(h^0 \to \tau^\pm \mu^\mp) \sim \frac{1}{N_c} \frac{m_\tau^2}{m_b^2} \frac{\cos^2(\alpha-\beta)}{\cos^2\beta \sin^2\alpha} \times |\kappa_{32}|^2. \tag{2}$$

The LFV parameter for this interaction, $|\kappa_{32}|$, is experimentally constrained by the result of $\tau^- \to \mu^- \eta$ as[6,7],

$$|\kappa_{32}|^2 < 0.3 \times 10^{-6} \times \left(\frac{m_A}{150\mathrm{GeV}}\right)^4 \left(\frac{60}{\tan\beta}\right)^6. \tag{3}$$

This shows that the bound is relaxed for larger m_A and smaller $\tan\beta$. The LFV parameter $|\kappa_{32}|$ is a function of the SUSY parameters, and its value does not depend on the absolute values of the SUSY parameters but on their ratio μ/m_{SUSY}, where μ is the higgsino mass and m_{SUSY} is the typical scale of the SUSY particles[4]. Therefore, the effect of this interaction does not decouple even in the large m_{SUSY} limit as long as the ratio is set to be of $\mathcal{O}(1)$. Let us consider the following parameter sets:

Case 1: $\tan\beta = 60$, $\mu = 25$ TeV,
$M_1 \sim M_2 \sim m_{\tilde{\ell}_{L_{\mu,\tau}}} \sim m_{\tilde{\ell}_{R_{\mu,\tau}}} \sim m_{\tilde{\nu}_{L_{\mu,\tau}}} \sim \sqrt{|(\Delta m^2_{\tilde{l}_L})_{32}|} \sim 2$ TeV,
$M_Q \sim 10$ TeV and $M_{U,D} \sim A_{t,b} \sim 8$ TeV,

Case 2: $\tan\beta = 60$, $\mu = 10$ TeV,
$m_{\tilde{\ell}_{L_{\mu,\tau}}} \sim m_{\tilde{\nu}_{L_{\mu,\tau}}} \sim \sqrt{|(\Delta m^2_{\tilde{l}_L})_{32}|} \sim 1.2$ TeV, $m_{\tilde{\ell}_{R_{\mu,\tau}}} \sim 0.9$ TeV,
$M_1 \sim 1$ TeV, $M_2 \sim 0.8$ TeV, $M_Q \sim 5$ TeV and $M_{U,D} \sim A_{t,b} \sim 3$ TeV,

where $M_{1,2}$ are the gaugino masses for $U(1)_Y$ and $SU(2)_L$, respectively, $m_{\tilde{\ell}}$ and $m_{\tilde{\nu}}$ are the masses of the charged slepton and the sneutrino, M_Q, M_U, M_D, and $A_{t,b}$ are the soft SUSY breaking parameters for the squark sector. In these examples, the photon-associated penguin diagrams decouple, and only the Higgs-mediated LFV coupling can contribute to $\tau^- \to \mu^- \eta$. For Case 1 and Case 2, we obtain $|\kappa_{32}|^2 \sim 8.4 \times 10^{-6}$ and 3.8×10^{-6}, and they are allowed experimentally for $m_A > 350$ GeV and $m_A > 280$ GeV, respectively. The branching ratio can be as large as 10^{-4} (See Fig.1). The mass of the lightest Higgs boson is fixed to be 123 GeV in both cases.

3 Signal at a Linear Collider

In order to study the LFV Higgs decay, the Higgsstrahlung process is appropriate because of its simple kinematic structure:

$$e^+e^- \to Zh^0 \to Z\tau^\pm\mu^\mp. \tag{4}$$

[a] A full 1-loop calculation is shown in Ref.[5].

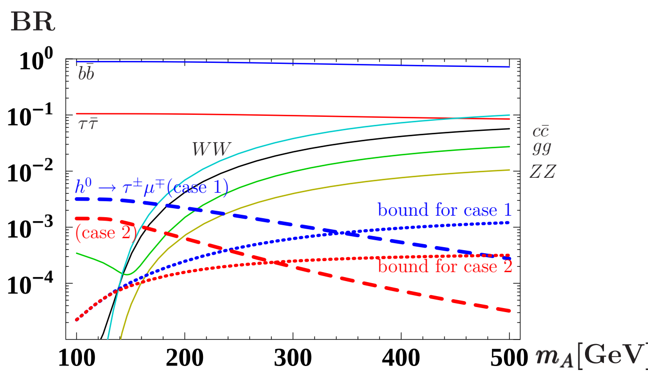

Figure 1: The branching ratio of the $h^0 \to \tau^\pm\mu^\mp$ event for $m_h = 123$ GeV (dashed curve). The upper limit from $\tau^- \to \mu^-\eta$ result is also shown (dotted curve).

We can identify the signal by using the recoil momentum of the Z boson, without measuring the momentum of the tau lepton. A large part of the background can be reduced by the invariant mass cut. However, there remain irreducible backgrounds which we call *the fake signals.* They are induced via

$$e^+e^- \to Zh^0 \to Z\tau^\pm\tau^\mp \to Z\tau^\pm\mu^\mp\nu\bar{\nu}. \tag{5}$$

Among the events of Eq.(5), those which mimic the τ-μ pair production are regarded as the fake signals. We assume that the integrated luminosity is 1,000 fb^{-1} and that $\sqrt{s}$ is optimally tuned for the Higgs production via the Higgsstrahlung. We categorize the signal $Z\tau\mu$ into two groups depending on the decay products of the Z boson: one is $jj\tau\mu$ where j is the hadronic jet, and the other is $\ell\ell\tau\mu$ where ℓ denotes electron or muon. The resolution of the Z boson momentum reconstructed from the hadronic jets is expected to be 3 GeV and that from the lepton pair is 1 GeV, respectively. In Case 1, the numbers of $jj\tau\mu$ and $\ell\ell\tau\mu$ are evaluated as $N^{\rm signal}_{jj\tau\mu} = 118$ and $N^{\rm signal}_{\ell\ell\tau\mu} = 11$. The fake signal is also evaluated as $N^{\rm fake}_{jj\tau\mu} = 460$ and $N^{\rm fake}_{\ell\ell\tau\mu} = 15$. The combined significance, $N^{\rm signal}/\sqrt{N^{\rm fake}}$, can reach to 6.3 at $m_A \simeq 350$ GeV. In Case 2, the significance is at most large as 2.0 at $m_A \simeq 280$ GeV.

4 Summary

We have studied possibility for the direct measurement of the LFV Yukawa coupling at a LC in the framework of the MSSM. The direct measurement of

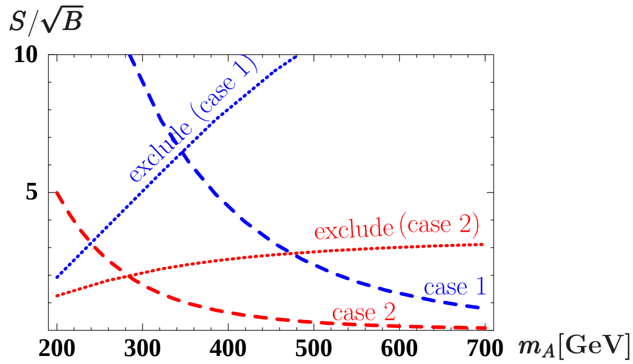

Figure 2: The significance of the signal event (dashed curve). The upper limit from the $\tau^- \to \mu^- \eta$ result is also shown (dotted curve).

the LFV Yukawa coupling could be complementary to the measurement of the other types of the LFV couplings. We have estimated the significance of the signal process, $e^+e^- \to Zh^0 \to Z\tau^\pm\mu^\mp$, at a LC with a high luminosity. The signal can be identified by using the recoil of the Z boson without measuring the momentum of the tau lepton. A large part of the backgrounds is expected to be reduced by appropriate kinematic cuts. We have found that the signal can be marginally visible. Needless to say, a more realistic simulation analysis is necessary.

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